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Hershey et al.

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[54] **PARALLEL DATAWORD MODULATION SCHEME**

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[51] **Int. Cl.**^{6} **H04L 27/00**

[52] **U.S. Cl.** **375/259**; 375/279

[58] **Field of Search** 375/259, 260, 375/261, 239, 363, 364, 365, 368, 279, 308, 329; 455/59, 60, 61; 370/112, 12, 18, 57, 121, 122

[56] **References Cited**

U.S. PATENT DOCUMENTS

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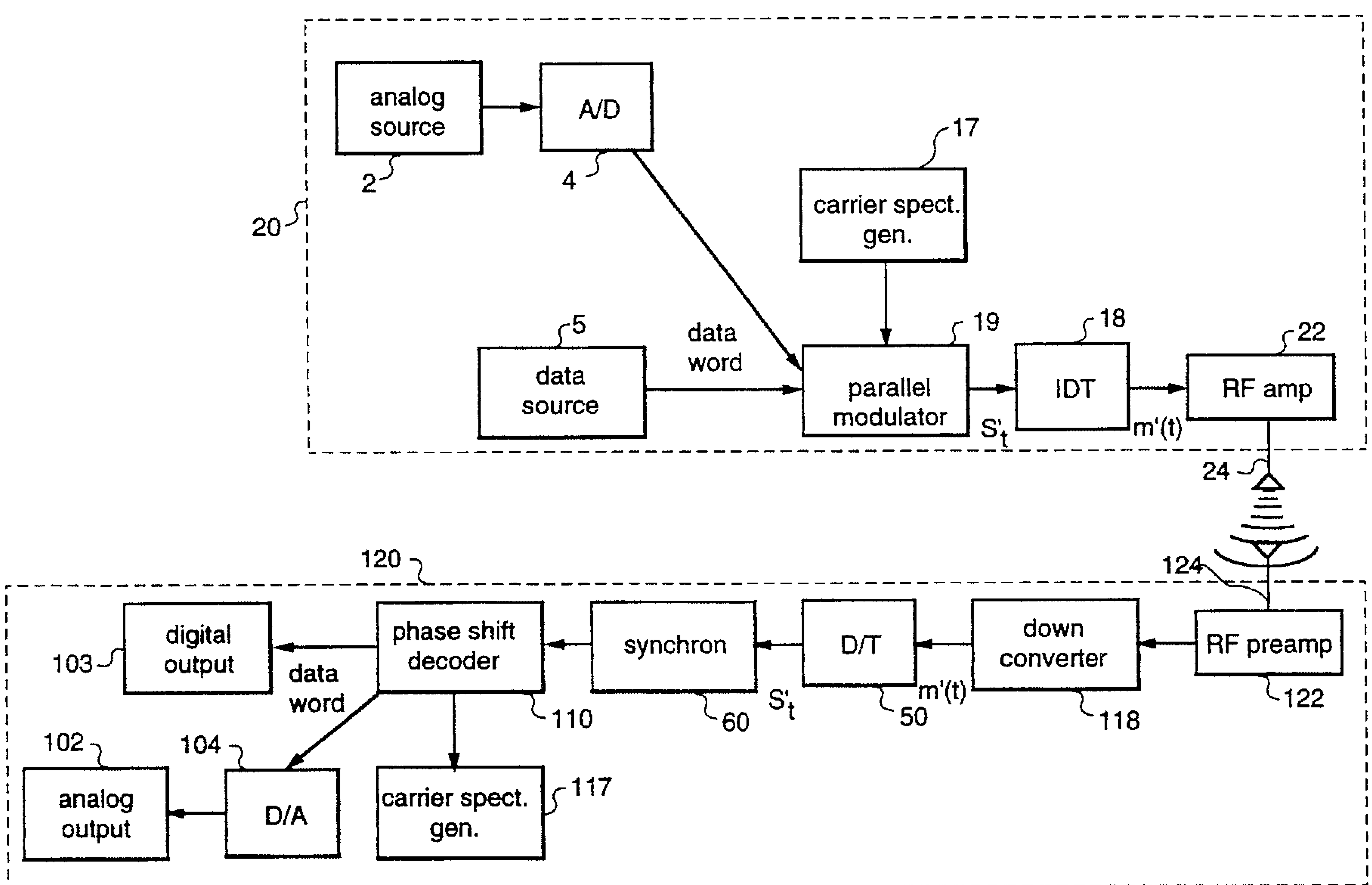
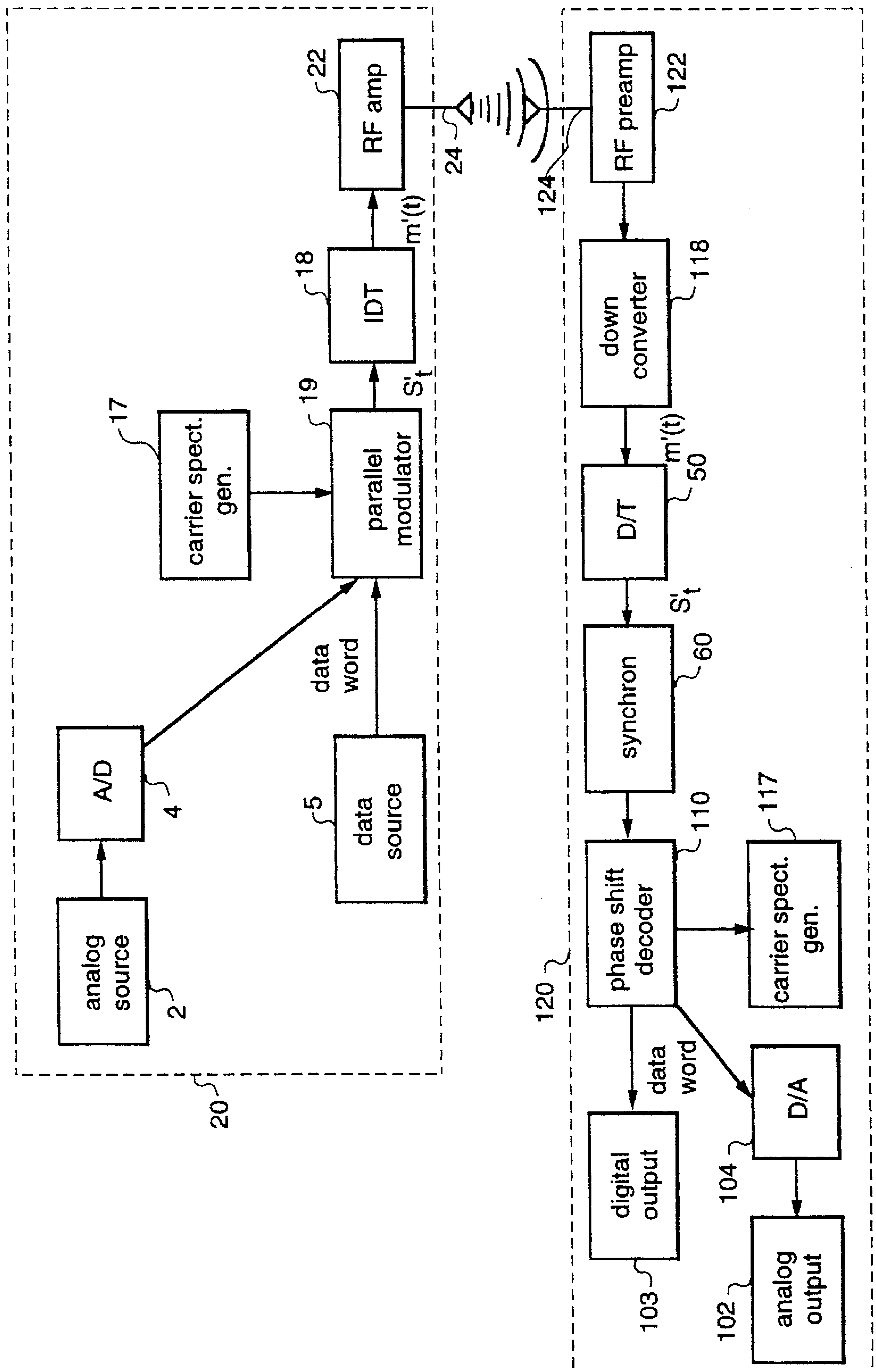
[57] **ABSTRACT**

Data words are transmitted over a radio channel with a novel modulation scheme which transmits data in parallel. An entire data word is modulated by separating a carrier frequency band into a number of discrete 'tones'. Tone T_1 is set to a zero phase shift in order to provide timing in synchronization of the signal. The remaining tones are phase shifted according to a predetermined convention, thereby encoding the bits of the data word. The phase shifts for all tones comprises a spectrum which is transmitted to a receiver simultaneously. A receiver monitors tone T_1 for zero phase shifts to provide synchronization of the signal. The remaining tones are analyzed for their phase shift to provide bits which are assembled into a transmitted data word. Since the bits are transmitted in parallel as the data word, as opposed to conventional modulation schemes, the throughput is increased.

2 Claims, 2 Drawing Sheets





analog source
2
A/D
4
data source
5
data word
carrier spect. gen.
17
parallel modulator
19
S'_t
IDT
18
$m'(t)$
RF amp
22
24
20
RF preamp
122
124
down converter
118
$m'(t)$
D/T
50
S'_t
synchron
60
phase shift decoder
110
carrier spect. gen.
117
data word
D/A
104
digital output
103
analog output
102
120

FIG. 1

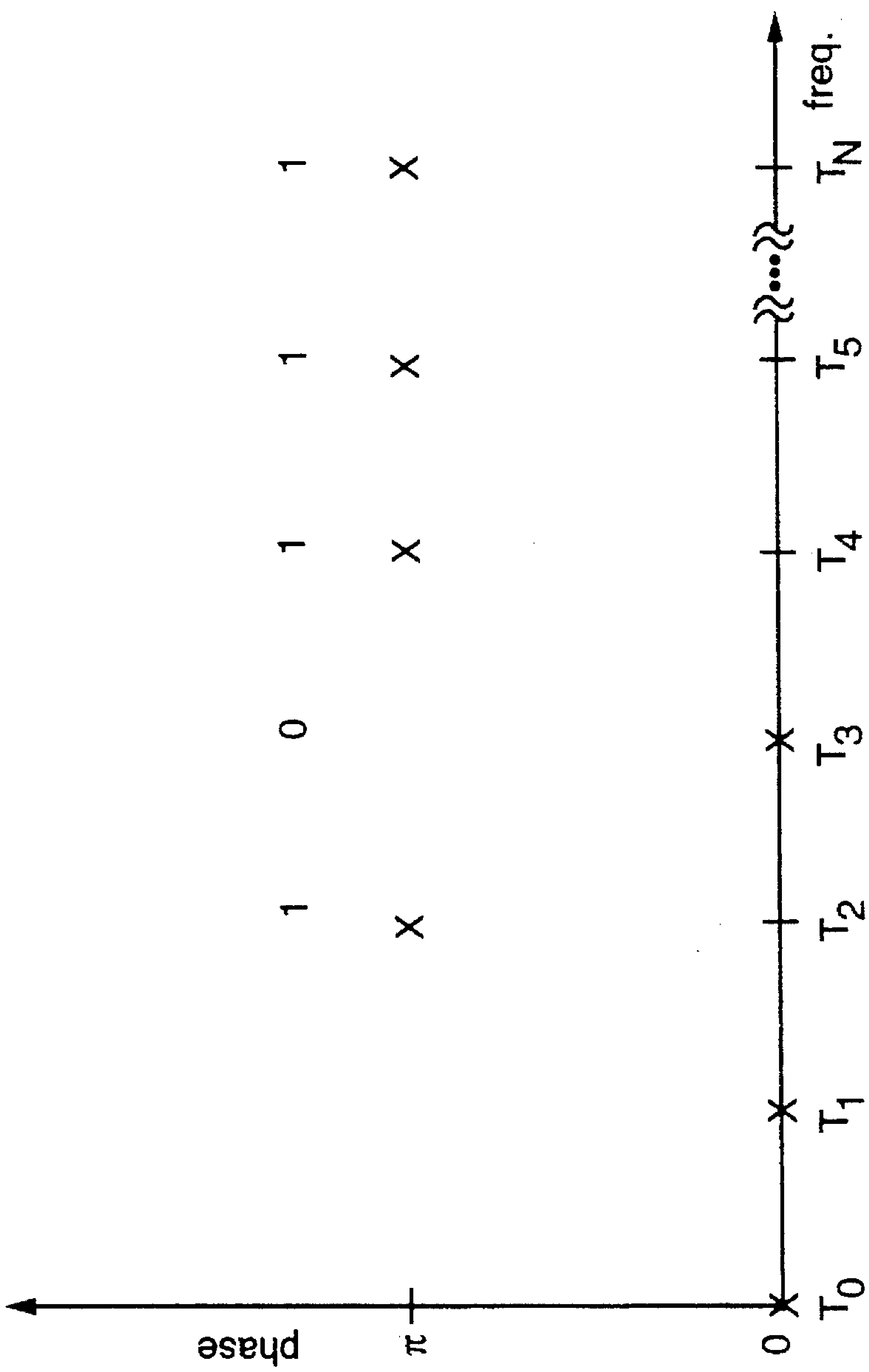


FIG. 2

PARALLEL DATAWORD MODULATION SCHEME

CROSS REFERENCE TO RELATED APPLICATIONS

This invention is related to U.S. patent applications Ser. No. 08/267,347, filed Jun. 29, 1994, "New Mobile Telecommunications Device and Service" by Amer Hassan, John Hershey, Howard Lester, Charles Puckette; Ser. No. 08/267,328, filed Jun. 29, 1994, "Datagram Communication Service over a Cellular Telephone Network" by John Hershey, Amer Hassan; Ser. No. 08/267,348 filed Jun. 29, 1994, "Datagram Message Communication Service Employing a Hybrid Network" by John Hershey; all assigned to the present assignee.

BACKGROUND OF THE INVENTION

1. Scope of the Invention

The present invention relates to digital radio modulation and more particularly, modulation of a data word in parallel.

2. Description of Related Art

Data or digitized analog information, is typically transmitted via radiowaves from a transmitter to a receiver. There are many ways of modulating the data to encode the digital information. One such way is to map data bits to phase shifts of a carrier wave. Therefore, a carrier wave has phase shifts which are modulated according to the input data transmitted and received at a receiver which then identifies the phase shift and the carrier signal to recover the encoded data.

Two such types of modulation are quadrature phase shift keyed (QPSK) modulation, and differential quadrature phase shift keyed (DQPSK) modulation.

There are also frequency modulation schemes in which data is encoded as the frequency of the carrier such as frequency shift keying (FSK) and continuous FSK (CPFSK).

There are also amplitude modulation schemes such as two or four level amplitude modulation (AM), and quadrature amplitude modulation (QAM).

In each of the above modulation schemes, a change in the frequency, phase, or amplitude modulates a single-bit, or several bits, of information being transmitted sequentially.

OBJECTS OF THE INVENTION

It is an object of the present invention to transmit several data bits in parallel and provide an improved data communication system.

It is another object of the present invention to provide a radio transmission system which provides greater throughput than conventional modulation schemes.

SUMMARY Of THE INVENTION

Digital information, in the form of data words are transmitted in parallel over a radio channel.

A carrier signal spectrum is synthesized and divided into a number of carrier tones with one carrier tone being used for synchronization and the phase of each of the other carrier tones each representing a bit value of the data word.

The carrier tones are phase shifted by a predetermined phase shift if the corresponding bit has a value of '1', and not shifted or shifted by a second predetermined phase shift, if the value of the corresponding bit is '0' to result in data word tones.

The data word tones and the synchronization tone are synthesized by using an inverse transform to produce a time-varying radio signal and transmitting the radio signal to a receiver.

At the receiver, the radio signal is transformed into the frequency domain. The synchronization tone is monitored by the receiver to determine synchronization and separate the radio signal into data word intervals each pertaining to a data word. The spectrum of the radio signal for each data word interval is transforming into the frequency domain and sectioned into signals representing each data bit.

The effect of the receiver processing is that each tone is compared to a synthesized carrier tone to determine the phase shift and decode a bit value. The bit values are assembled into a data word. Since many bit values are encoded by phase shifts, many bits may be transmitted simultaneously.

BRIEF DESCRIPTION OF THE DRAWINGS

While the novel features of the invention are set forth with particularity in the appended claims, the invention, both as to organization and content, will be better understood and appreciated, along with other objects and features thereof, from the following detailed description taken in conjunction with the drawings, in which:

FIG. **1** is a simplified block diagram of a digital radio communication system according to the present invention.

FIG. **2** is a frequency vs. phase diagram illustrating a data word modulation scheme according to the present invention.

DETAILED DESCRIPTION OF THE INVENTION

FIG. **1** is a block diagram of a presently preferred embodiment of the present invention showing a transmitter **20** and a receiver **120**. Digital information, in the form of parallel data words, desired to be transmitted is provided by a data source **5**. The digital information may also be provided by an analog source **2** that is sampled by an analog to digital (A/D) converter **4**, as shown in phantom.

A carrier spectrum generator **17** synthesizes a complex spectrum comprised of amplitudes and phases for a carrier signal to be employed in transmitting the data words.

A parallel modulator **19** coupled to the carrier spectrum generator receives the carrier signal spectrum and sections it into frequency bands defined as "tones". The tones are numbered from a zeroeth frequency, T_0, to a last tone T_N, as shown in FIG. **2**. It is envisioned that there will be $\mathbf{2}^M$ tones where M is 5 or 6. In the complex frequency domain, each tone is represented by an amplitude and a phase.

The data words desired to be transmitted are provided to parallel modulator and used to alter the phase of tones T_1 through T_N according to a predetermined modulation convention. In the example of FIG. **2**, a '**0**' is modulated as a zero phase shift of a tone and a '**1**' is a π phase shift of a tone. T_0 is the DC term and is not used. T_1 is set to zero phase shift to allow synchronization of the radio signal. The first four bits of the data word being transmitted, T_2, T_3, T_4, T_5, in FIG. **2** are '**1011**' with the last bit, T_N being '**1**'.

In FIG. **1**, the entire set of tones for a data word of time period 't' is spectrum S_t. Spectrum S_t is converted to a time-varying radio message signal m(t) by an inverse discrete transform (IDT) unit **18**. The inverse discrete transform may be an inverse Fourier, inverse Hadamard, or inverse Discrete Cosine as transform.

Message signal m(t) is passed to a radio frequency (RF) amplifier **22** which creates an RF signal transmitted through antenna **24** which is received by antenna **124** of receiver **120**.

The transmitted signal is sensed by a receiving antenna **124**, passed to an RF preamplifier **122** and heterodyned by a down converter **118** to provide an intermediate frequency (IF) signal, m'(t) which is the equivalent of the message signal m(t).

A discrete transform unit **50**, performs a transform which is the inverse of the operation executed by IDT unit **18**, and transforms the message signal m'(t) into a spectrum S'_t comprised of tones T'_2, T'_3, T'_4, T'_5, . . . T'_N, which correspond to tones of the employed in parallel modulator **19** in transmitter **20**.

Synchronization unit **60** monitors the S'_t signal to determine regularly spaced '**0**' phase shifts in tone T'_1. This provides the synchronizing required to distinguish a spectrum, S'_{t1}, of a data word from time t_1 from a spectrum S'_{t2} from time t_2. Synchronizer separates these spectra and provides them to phase shift decoder **110**.

A carrier spectrum generator **117** synthesizes a complex spectrum for a carrier signal to be employed in transmitting the data words comprised of amplitudes and phases, the same as the carrier spectrum generator in transmitter **20**.

Phase shift decoder **110** determines phase shifts for each tone, which may be determined by comparing the phase of each tone with a corresponding tone from carrier spectrum generator **117**. Phase shift decoder **110** assembles a data word representing these phase shifts. An output device **103** then utilizes the decoded data words.

In an alternative embodiment, the output device may also be a digital to analog (D/A) converter **104** which converts the data words into an analog signal which is utilized by an analog output device **102**.

While only certain preferred features of the invention have been illustrated and described herein, many modifications and changes will occur to those skilled in the an. It is, therefore, to be understood that the appended claims are intended to cover all such modifications and changes as fall within the true spirit of the invention.

What is claimed is:

1. A method of transmitting digital information over a radio frequency channel comprising the steps of:

a) assembling data to be transmitted into data words each having N bits;

b) transforming a carrier signal into a frequency spectrum in a frequency domain;

c) separating the frequency spectrum of the carrier signal into a plurality of tones, one corresponding to a synchronization reference and the remainder each corresponding to a bit of a data word to be transmitted;

d) shifting tones by a predetermined phase shift if the corresponding bit has a value of '$\mathbf{1}^1$ for a first data word to be transmitted;

e) inverse transforming the tones into a radio signal;

f) transmitting a radio signal incorporating the phase shifts of the tones for the first data word at time t;

g) repeating steps (d)–(f) for all data words to be transmitted;

h) receiving the radio signal at a receiver;

i) transforming the received radio signal into a received frequency spectrum;

j) synchronizing the received radio signal so as to identify portions of the radio signal corresponding to different data words; and

k) separating the received radio signal into data word intervals each corresponding to data word, and for each data word interval:

1. separating the spectrum of the data word interval into data word tones,
2. identifying the phase shift of each data word tone to identify bit values of the data word, and
3. constructing the data word from the bit values.

2. The method of transmitting digital information of claim **1** wherein the step of identifying the phase shift of each tone comprises the steps of:

a) synthesizing a frequency spectrum of the carrier signal;

b) separating the carrier signal spectrum into carrier signal tones to correspond to the data word tones;

c) comparing the phase of the carrier signal tones with the phase of the data word tones to result in a phase difference;

d) assigning bit values to phase differences.

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